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WIND-TUNNEL INVESTIGATION OF AN NACA 23012

AIRFOIL WITH A 30-PERCENT-CHORD MAXWELL

SLAT AND WITH TRAILING-EDGE FLAPS

By John G. Lowry and John W. McKee

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Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

WIND-TUNNEL INVESTIGATION OF AN NACA 23012

AIRFOIL WITH A 30-PERCENT-CHORD MAXWELL

SLAT AND WITH TRAILING-EDGE FLAPS

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SUMMARY

An investigation has been made in the NACA 7- by 10-foot wind tunnel of an NACA 23012 airfoil with a 30 percent-chord Maxwell leading-edge slat and with a slotted and a split flap. The purpose of the investigation was to determine the optimum slot gap of the Maxwell slat for, and the aerodynamic section characteristics of, the airfoil with several deflections of both types of flap. Curves of lift, drag, and pitching-moment characteristics for selected optimum arrangements are presented.

As the slot gap was increased up to the optimum the profile drag increased except in the range near maximum lift coefficient, the pitching moment became increasingly negative, and the lift coefficient at a given angle of attack decreased. A slot gap of 3.5 to 4 percent of the wing chord gave the greatest increase in the angle of attack at the stall and in maximum lift coefficient for all flap deflections.

INTRODUCTION

To increase the efficiency and safety of airplanes it is desirable to have means of increasing the maximum lift of airfoils and of increasing and regulating the angle at which they stall. Leading-edge slots are one of the few devices that have been found capable of increasing both the maximum lift and the angle of attack at the stall.

The fixed leading-edge slot (reference 1) is an integral part of the wing and has no moving parts. This slot is the simplest type

but has the disadvantage of increasing the drag in the normal flying range. It may be advantageous, however, where ruggedness and simplicity are essential. The Handley Page leading-edge slot (references 2 and 3) and the Maxwell leading-edge slot (reference 4) have more favorable characteristics in the slow-speed high angle-of-attack range when they are open, and in addition increase the drag in the normal flying range only slightly when they are closed. The Maxwell slot (fig. 1) is the simpler in operation, as it is operated by rotating the slot about a fixed point.

This investigation was made to determine the optimum slot gap of the Maxwell slot for, and the aerodynamic section characteristics of, an NACA 23012 airfoil with a 30-percent-chord Maxwell slot and with a slotted and a split flap.

MODELS

The 3-foot chord by 7-foot span airfoil, the Maxwell slot, and the slotted flap were built of laminated mahogany to the profiles of figure 2 and table I. The full-span split flap, which had a chord of 7.2 inches (20 percent of the airfoil chord), was built of 1/4 inch plywood. This flap was fastened to the airfoil with screws and the flap angles (0° to 60°) were set by triangular wooden blocks between the flap and airfoil. The full-span slotted flap had a chord of 9.238 inches (25.66 percent of the airfoil chord) and is designated as 2-h in reference 5. It was mounted on the main airfoil by three steel fittings that allowed flap deflections of 0° to 60° . The path of the flap nose point (the nose point of the flap is defined as the point of tangency of a line drawn perpendicular to the airfoil chord and tangent to the leading edge of the flap when neutral) was the optimum one reported in reference 5 (table II). The maximum width, or chord, of the Maxwell slot was 10.8 inches, 30 percent of the airfoil chord. It was mounted on the main airfoil by four steel fittings that allowed for slot gaps as great as 7 percent of the wing chord.

TESTS

The tests were made in the NACA 7- by 10-foot wind tunnel (references 5 and 6) at a dynamic pressure of 16.37 pounds per square foot corresponding to an air speed of about 80 miles per hour under standard sea-level conditions. The average test Reynolds number based on the chord of the airfoil with the slot and flap

retracted was 2,190,000; due to turbulence in the air stream the effective Reynolds number (for maximum lift coefficients) was approximately 3,500,000. The model completely spanned the closed test section of the wind tunnel so that two-dimensional flow was approximated (reference 5). Sufficient slot gaps of the Maxwell slat were tested with most flap deflections to determine the trend of the characteristics and the optimum slot gap for maximum angle of attack at the stall and for maximum lift. Data for the airfoil with the slot closed were taken from reference 5, because with the slot closed the basic airfoil contour is established. When the slotted flap was fully retracted the flap slot gap was sealed and faired to the basic airfoil contour as recommended in reference 5.

RESULTS AND DISCUSSION

Coefficients

All test results are given in standard nondimensional section coefficient form (corrected as explained in reference 5) as follows:

c_l	section lift coefficient (l/qc)
c_{d_o}	section drag coefficient (d_o/qc)
$c_{m(a.c.)_o}$	section pitching-moment coefficient about the aerodynamic center of the airfoil with flap and slat retracted ($m(a.c.)_o/qc^2$) (See reference 5.)

where

l	section lift
d_o	section profile drag
$m(a.c.)_o$	section pitching moment
q	dynamic pressure ($\frac{1}{2}\rho V^2$)
c	chord of airfoil with slat and flap retracted
c_f	flap chord (projected width on airfoil chord line)
c_s	slat chord (maximum width)

and

α_o	angle of attack for infinite aspect ratio
δ_f	flap deflection
$c_{l_{max}}$	maximum lift coefficient
$\alpha_{c_{l_{max}}}$	angle of attack for maximum lift coefficient

Precision

The accuracy of the various measurements is believed to lie within the following limits:

α_o	$\pm 0.1^\circ$	$c_{d_o}(c_l=1.0)$	± 0.0006
$c_{l_{max}}$	± 0.03	$c_{d_o}(c_l=2.5)$	± 0.002
$c_{m(a.c.)_o}$	± 0.003	δ_f	$\pm 0.2^\circ$
$c_{d_{o_{min}}}$	± 0.0003	Flap position	$\pm 0.001c$
Slot gap		$\pm 0.001c$	

No attempt was made to determine the effect of flap or slat fittings.

Effects of Slot Gap on Plain Airfoil

The effects of the Maxwell slot on the airfoil aerodynamic section characteristics were similar to those reported in reference 4. Figure 3 shows the effect of the slot gap on the aerodynamic section characteristics of the airfoil without flaps. A slot gap of 0.035c gave the greatest $c_{l_{max}}$ and $\alpha_{c_{l_{max}}}$. The

maximum section lift coefficient increased from 1.55 at $\alpha_{c_{l_{max}}} = 15.3^\circ$ for the plain airfoil (reference 5) to 2.20 at $\alpha_{c_{l_{max}}} = 25.2^\circ$ for

the airfoil with a 0.30c Maxwell slat. The pitching-moment coefficient became increasingly negative as the slot was opened, indicating that the center of pressure moved rearward. The slope of the lift

curve over the positive lift range remained practically constant, although α for a given c_l increased as the gap increased. The drag coefficient increased slowly in the range above $c_l = 0.6$ as the slot was opened but more rapidly below $c_l = 0.6$.

Effect of Slot Gap with Various Configurations

The effect of slot gap on $c_{l_{\max}}$ and $\alpha_{c_{l_{\max}}}$ is shown on figure 4 for the airfoil with both the slotted and the split flap for various flap deflections. As the flap deflection was increased the $\Delta c_{l_{\max}}$ produced by a 0.035c slot gap decreased from 0.65 with no flap deflection to approximately 0.30 with flap deflected for maximum lift. In every case the optimum slot gap increased the angle of attack for maximum lift coefficient approximately 10° . The airfoil with the split flap had the greatest $c_{l_{\max}}$ and $\alpha_{c_{l_{\max}}}$ when the slot gap was 0.035c for most flap deflections. This value agrees very well with the results reported in reference 4. The airfoil with the slotted flap had the greatest $c_{l_{\max}}$ when the slot gap was 0.035c and the greatest $\alpha_{c_{l_{\max}}}$ when the slot gap was 0.04c for most flap deflections. The data for these three optimum conditions are plotted in figures 5, 6, and 7. A comparison of these figures with data given in reference 5 shows that opening the slot to the optimum gap increased the pitching-moment coefficient negatively an average of about 0.04 over the high lift range for all flap deflections.

Comparison of Profile Drag

A comparison of profile-drag characteristics of several airfoil-slat-flap combinations is given in figure 8 as envelope polars. The plain airfoil had the lowest profile drag for lift coefficients below 0.9. The airfoil with slotted flap 2-h and no leading-edge slot is shown to have the lowest profile drag in the range $c_l = 0.9$ to 2.8. Above $c_l = 2.8$, which was the maximum lift coefficient for the airfoil with the flap, the airfoil with slotted flap 2-h and the Maxwell slat with a 0.035 slot gap had the lowest profile drag. Opening the gap to 0.04c gave slightly higher profile drag over the entire range. The 0.20c split flap with the 0.035c slot gap had considerably higher profile drag than the corresponding slotted flap combination above $c_l = 1.2$.

CONCLUDING REMARKS

For the arrangements tested a slot gap of 3.5 to 4 percent of the wing chord gave the greatest increase in maximum lift coefficient and angle of attack at the stall. The increment of maximum lift coefficient caused by the slot varied from 0.65 with flaps neutral to approximately 0.30 with the flaps deflected for maximum lift; the angle of attack at the stall was increased approximately 10° in all cases. As the slot gap was increased up to the optimum the profile drag increased except in the range near maximum lift, the pitching moment became increasingly negative, and the lift coefficient at a given angle of attack decreased.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics,
Langley Field, Va., June 16, 1941.

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2. Anon.: Résumé of Investigations Made on Handley Page Slots and Flaps. A.C.I.C., vol. VII, no. 639, Matériel Div., Army Air Corps, 1929.
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TABLE I

ORDINATES FOR AIRFOIL, FLAP AND SLAT SHAPES

[Stations and ordinates in percent airfoil chord]

NACA 23012 airfoil			Slotted flap 2-h		
Station	Upper surface	Lower surface	Station	Upper surface	Lower surface
0	---	0	0	-1.29	-1.29
1.25	2.67	-1.23	.40	-.32	-2.05
2.5	3.61	-1.71	.72	.04	-2.21
5	4.91	-2.26	1.36	.61	-2.36
7.5	5.80	-2.61	2.00	1.04	-2.41
10	6.43	-2.92	2.64	1.40	-2.41
15	7.19	-3.50	3.92	1.94	---
20	7.50	-3.97	5.20	2.30	---
25	7.60	-4.28	5.66	---	-2.16
30	7.55	-4.46	6.48	2.53	---
40	7.14	-4.48	7.76	2.63	---
50	6.41	-4.17	9.03	2.58	---
60	5.47	-3.67	10.31	2.46	---
70	4.36	-3.00	15.66	1.68	-1.23
80	3.08	-2.16	20.66	.92	-.70
90	1.68	-1.23	25.66	.13	-.13
95	.92	-.70	Center of L.E. arc		
100	.13	-.13	0.91	-1.29	
L.E. radius: 1.58. Slope of radius through end of chord: 0.305			L.E. radius: 0.91		

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TABLE I -- Concluded

ORDINATES FOR AIRFOIL, FLAP AND SLAT SHAPES -- Concluded

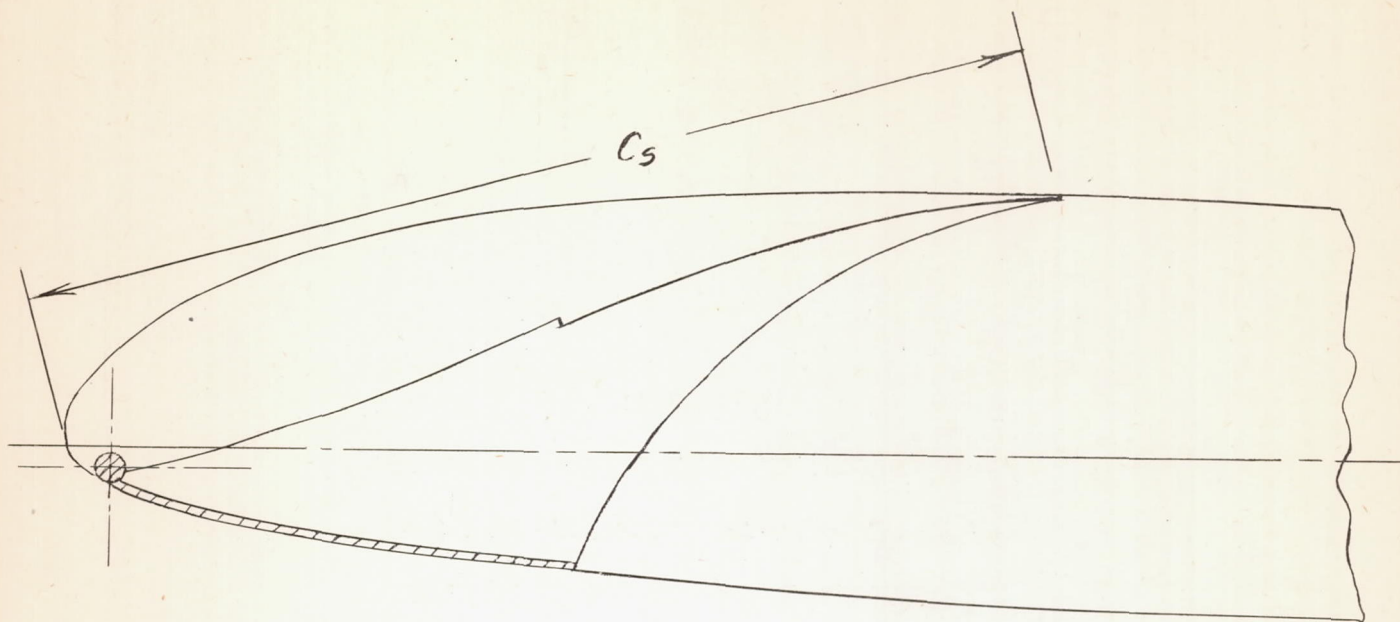
0.30c Maxwell Slat		
Station	Upper surface	Lower surface
0	---	0
1.25	2.67	-1.23
2	---	-1.20
2.5	3.61	---
4	---	-.69
5	4.91	---
6	---	.07
7.5	5.80	---
8	---	.88
10	6.43	1.70
15	7.19	---
16	---	4.28
20	7.50	5.68
24	---	6.67
25	7.60	---
29.02	7.56	7.46
L.E. radius = 1.58. Slope of radius through end of chord: 0.305		
Hinge radius center		
	1.40	-1.00

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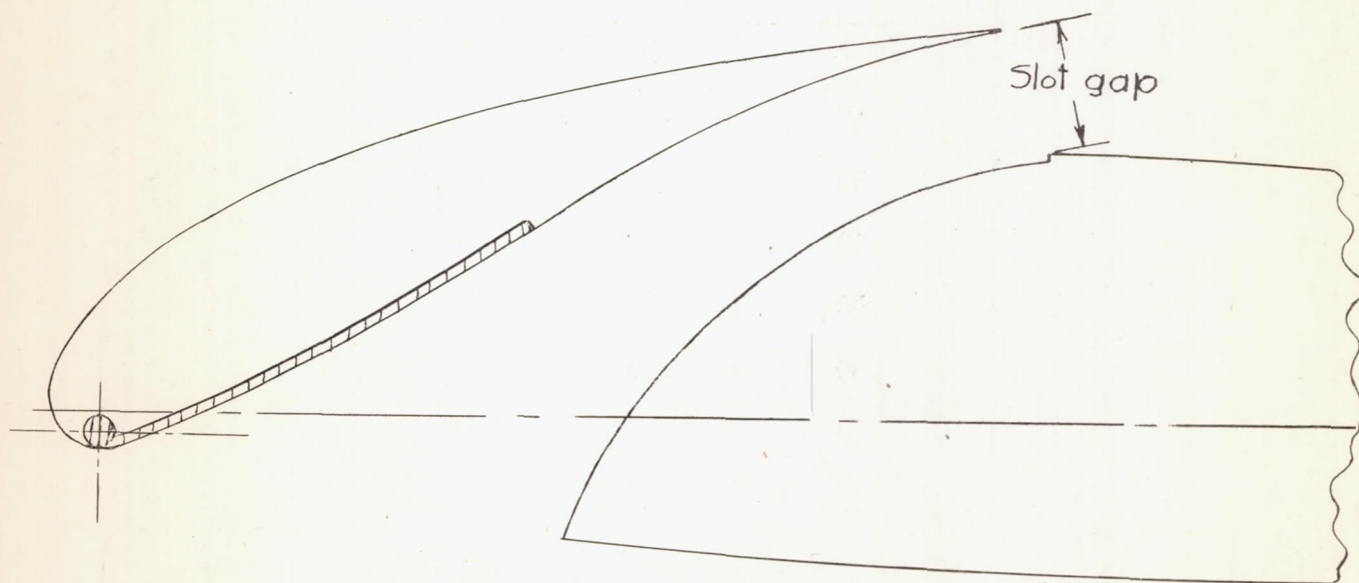
TABLE II
PATH OF NOSE OF SLOTTED FLAP FOR VARIOUS
FLAP DEFLECTIONS. DISTANCES MEASURED
FROM LOWER EDGE OF LIP IN PERCENT
AIRFOIL CHORD c

δ_f (deg)	x	y
0	8.36	3.91
10	5.41	3.63
20	3.83	3.45
30	2.63	3.37
40	1.35	2.43
50	.50	1.63
60	.12	1.48

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Slot closed



Slot open

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FIGURE 1:- Arrangement of Maxwell slot.

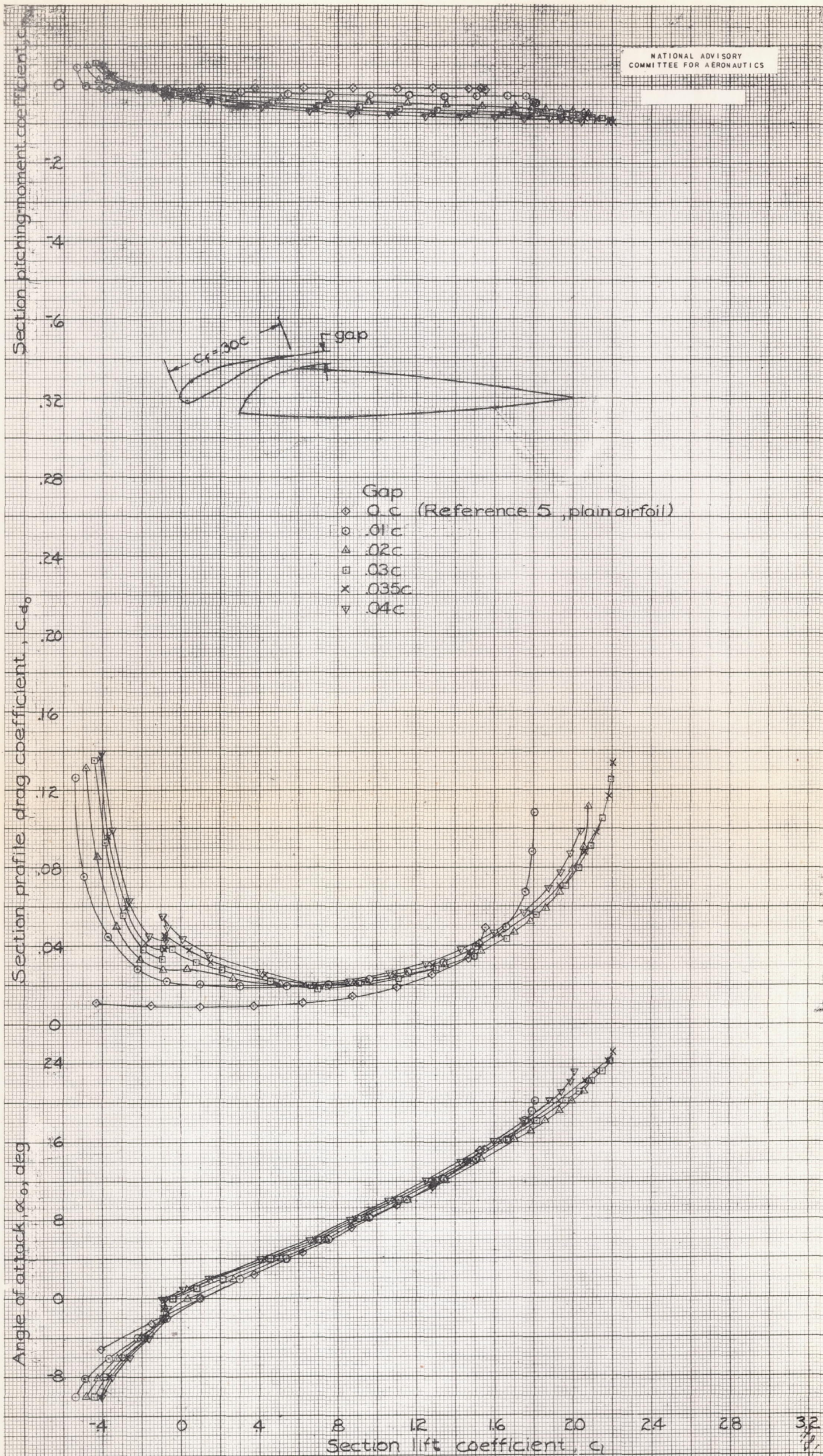


Figure 3.- Aerodynamic section characteristics of NACA 23012 airfoil with a 0.30c Maxwell slot with various slot gaps.

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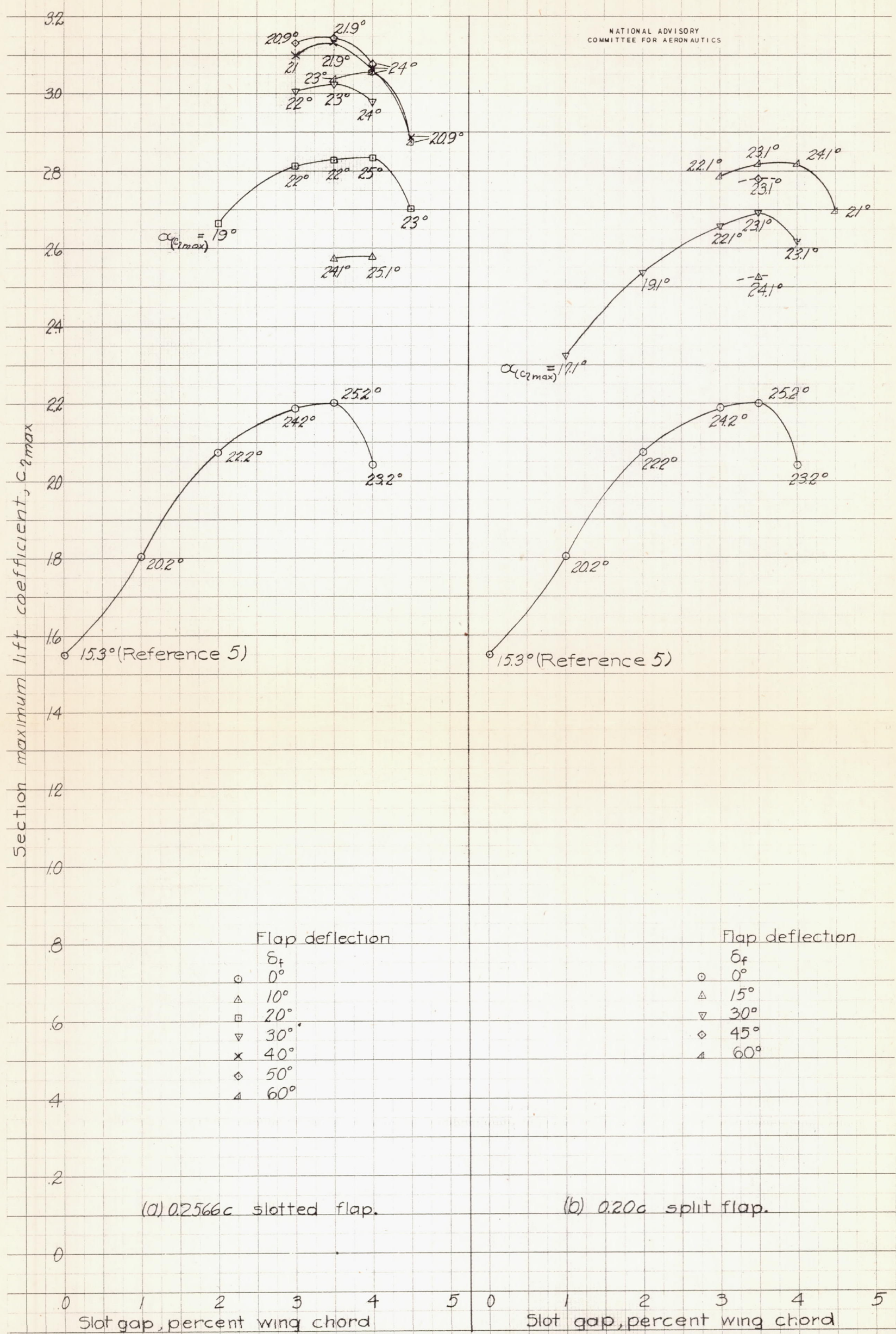


Figure 4.- Effects of slot gap on C_{lmax} and $\alpha_{C_{lmax}}$ of NACA 23012 airfoil with a 0.30c Maxwell slat and with a slotted and a split flap.

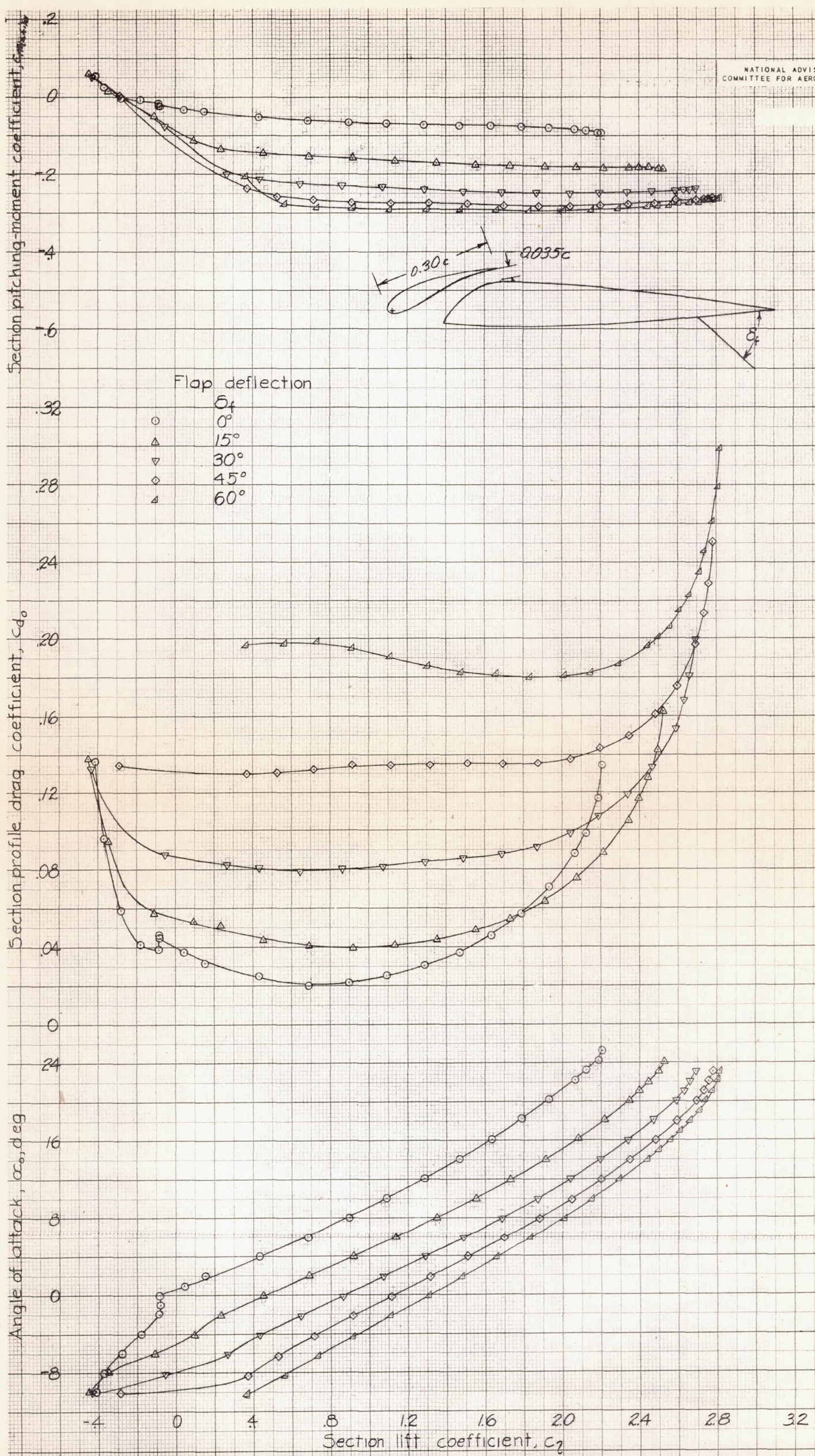


Figure 5.- Aerodynamic section characteristics of NACA 23012 airfoil with a 0.20c split flap and a 0.30c Maxwell slot. Slot gap = 0.035c.

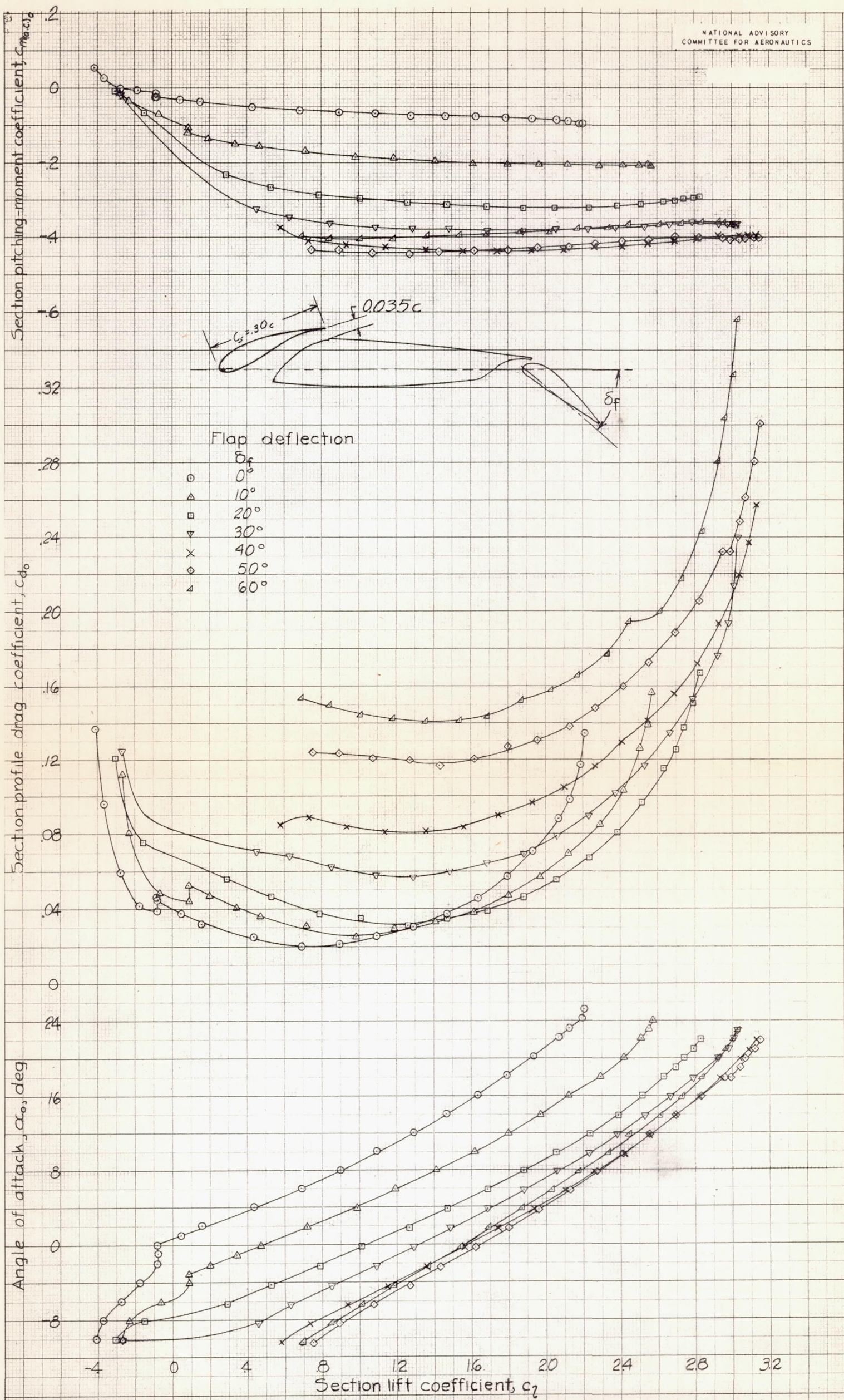


Figure 6. - Aerodynamic section characteristics of NACA 23012 airfoil with a 0.2566c slotted flap and a 0.30c Maxwell slat. Slot gap = 0.035c.

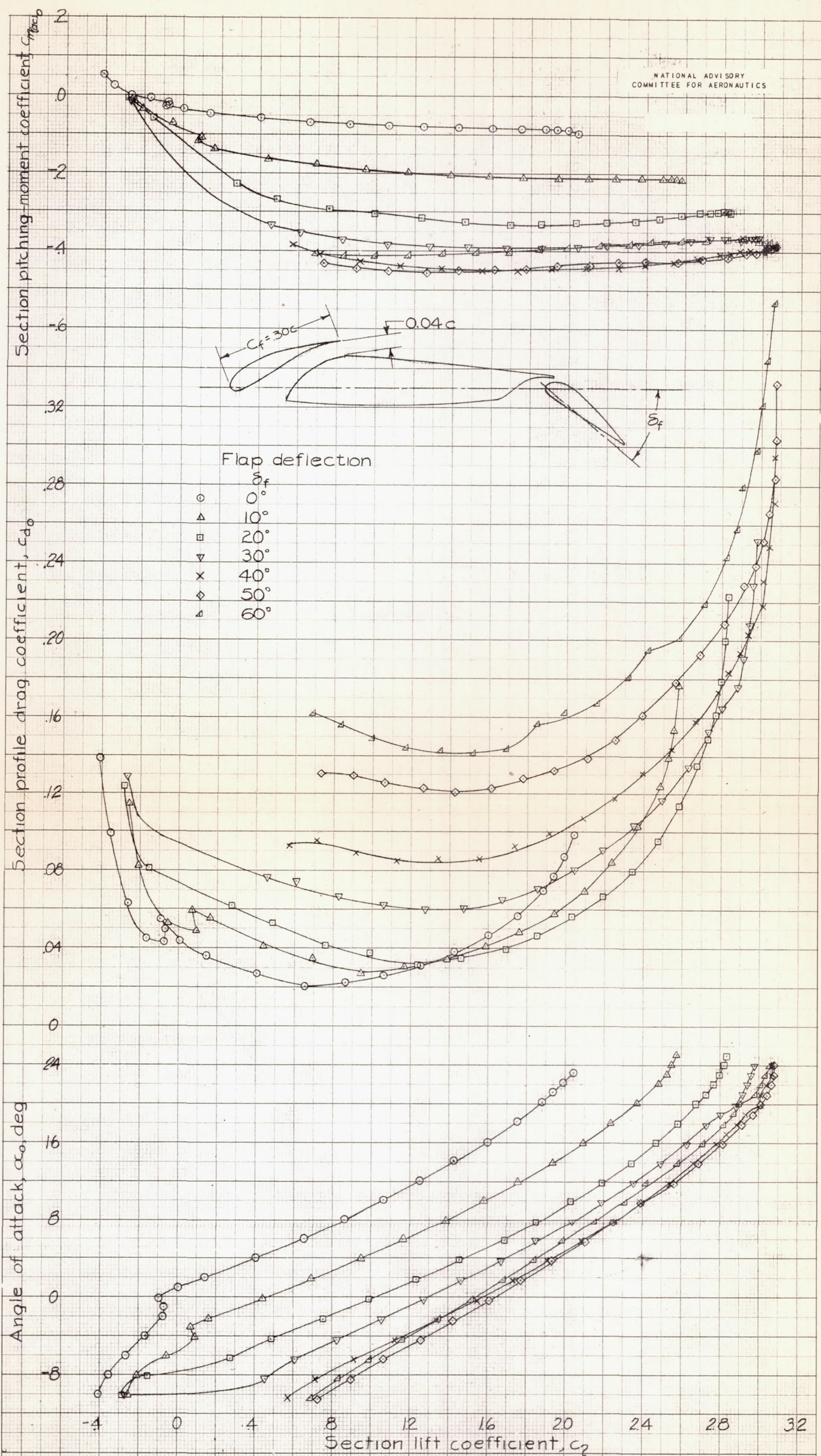


Figure 7.- Aerodynamic section characteristics of NACA 23012 airfoil with a 0.2566 c slotted flap and a 0.30 c Maxwell slot. Slot gap = 0.04 c .

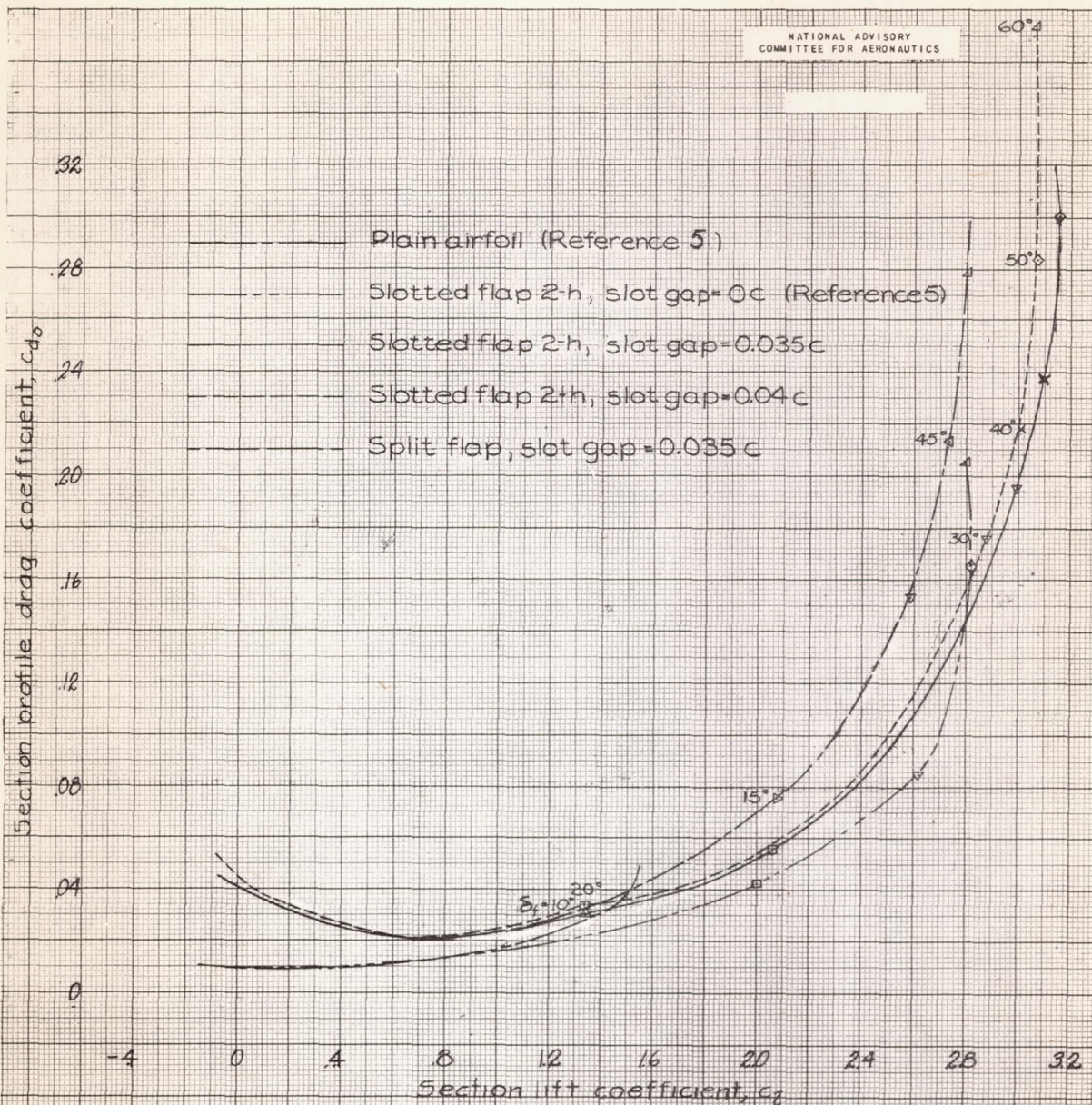


Figure 8.- Comparison of profile-drag coefficients of several airfoil-slat-flap combinations.

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